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THE CAUSES OF THE DECADENCE OF HEMLOCK AT THE MENOMINEE INDIAN RESERVATION, SHAWANO COUNTY, WISCONSIN

by

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In 1937 the Bureau of Entomology and Plant Quarantine, at the request of the Indian Service, United States Department of the Interior, began an investigation of the eastern hemlock borer, Melanophila fulvoguttata Harr., at the Menominee Indian Reservation in east-central Wisconsin. Hemlock forms an important part of the forest on this reservation of 230,000 acres, and in 1934 it was estimated that approximately 50,000,000 board feet of hemlock had died because of the drought conditions in the three seasons preceding. In 1936 the hemlock borer was reported to be in epidemic form and to be responsible for the death of a considerable volume of timber, which by 1936 was estimated to be not less than 135,000,000 board feet killed in five years.

The investigation in 1937 by L. E. Yeager was largely in the nature of a survey, and a series of 49 sample plots was established in stands of varying site conditions to determine the extent of the infestation. In the spring of 1938 the project was continued by the senior author on a more intensive basis than was possible the first season. The biology of the hemlock borer has been studied in detail and will be treated in a separate paper. The ecological phases, through the study

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of the sample plots established in 1937 and of an additional series of 6 growth-study plots established by the Indian Service in 1929, gave information which indicated the necessity of studying factors which were not immediately apparent to the eyes of the observers.[4]

During the course of the examination of these plots in 1938, it became increasingly apparent that many trees showing signs of decadence did not have a large enough population of borers to girdle them and cause death. At the same time fruiting bodies or the mycelial fans of the shoestring fungus, Armillaria mellea (Vahl.) Quel., were found at the bases of some of the trees. This fungus is generally considered to be secondary under forest conditions and its presence on these trees brought previous investigations by Spaulding and MacAloney[5] to the latter's mind. These investigations showed that the cause of the decadence of birch in cut-over areas in northern New England was due to certain organic factors and that the bronze birch borer and the shoestring fungus were essentially secondary agencies. Althoughthe causes contributing to the death of the hemlock were not, perhaps, entirely similar, the general aspects of the decadence in many of the hemlock stands in the Reservation suggested the probability that an intensive examination of the root systems of some of the trees would reveal the true cause of decadence and death. Accordingly, with the cooperation of the Forestry Department of the Reservation and the

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4. The authors gratefully acknowledge the cooperation of Richard Delaney, forester at the Menominee Indian Reservation, in making this study possible.

5. Spaulding, Perley and MacAloney, H. J. "A Study of Organic Factors Concerned in the Decadence of Birch on Cut-over Lands in Northern New England," Jour. Forestry, 26:1134 - 1149 . . 1931.

Indian Division of the Civilian Conservation Corps there, a root examination project was set up and carried out in July 1939. Removal of the soil from the root systems was accomplished by hydraulic means, as Spaulding and MacAloney had found that this was much quicker and involved less danger of root breakage than when the excavating was done by hand with picks, shovels, and trowels. A gasoline-powered, 5 h. p. typhoon type pump and 600 feet of 1 1/2-inch fire hose was supplied by the Forestry Department, and increased pressure was developed through the use of 1/4-inch brass nozzles. A "Y" connection placed in the main line, one hose length from the nozzles, permitted the use of two streams of water, each with about 75 pounds pressure per square inch at the nozzle. When the trees to be examined were within a few hundred feet of a stream and the terrain was not steep, the pump was set up at the bank; where this was not possible, a well was jetted in the soil, which in all cases was of a sandy or sandy-loam type. In order that the disease phases of the situation might be ~~cleared up~~ examined, the Division of Forest Pathology, Bureau of Plant Industry, gave assistance in the study of the fungi connected with the decadence.

The project was carried on for 30 working days, during which time the root systems of 27 hemlock trees were exposed and examined. Table 1 shows the condition of the roots and the amount of borer infestation of 16 of these trees, grouped according to successful attacks, unsuccessful attacks, and checks (those with practically no attacks). Ten of the remaining trees were overtopped and were washed out with the larger ones or were trees selected because of Armillaria infection alone. (Fig. 1.) In one instance a dead tree, from which beetles had emerged and which had been

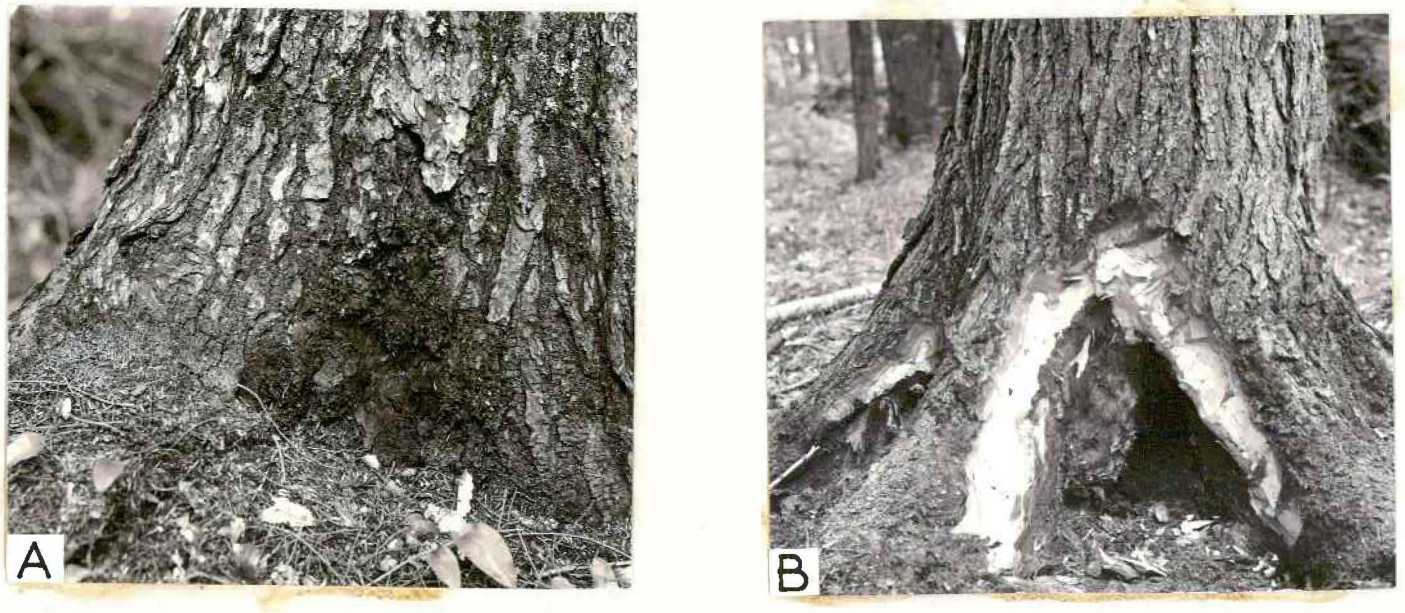

Figure 1. - A, A moist discoloration on the bark often indicates: B, the presence of infection by the shoestring fungus, Armillaria mellea.

dead so long that all of the root system and most of the cambium of the bole were dead, was examined in order to have a basis for comparison of advanced and early stages of root decadence. The trees were selected on slopes to facilitate the removal of the soil. The time required for washing out the root system of a large tree sufficiently to make the necessary observations was from 4 to 6 hours, depending on the gradient of the slope.

After the greater portion of the main root system of a tree was exposed, the total number of lateral roots of 2.5 inches and up in diameter at 5 feet from the stump was recorded. Ten of these roots were selected at random as a representative sample and were examined at intervals of 5 feet throughout their length by peeling away the bark and recording the condition of the cambium. From these data percentage figures representing the amount of living root system of each tree was calculated. (Table 1.) The feeding roots were also carefully examined, and it was found that in many cases they had been dead for some time. (Fig. 2.) Even under the most favorable conditions in the forest there is a certain amount of root mortality, particularly among shallow rooted species, and when the water table is lowered due to a prolonged drought, such as occurred at the Reservation from 1930 to 1937, it is obvious that this mortality is greatly increased. Study of the precipitation records at the three closest Weather Bureau stations, at Antigo, Shawano, and Wausau, which are located, airline, 20 miles northwest, 17 miles southeast, and 40 miles west respectively of the more centrally located Indian village of Neopit, shows that, with the exception of Shawano in 1931, the annual precipitation at each station was below normal for every year except 1934. (Table 2.) In addi-

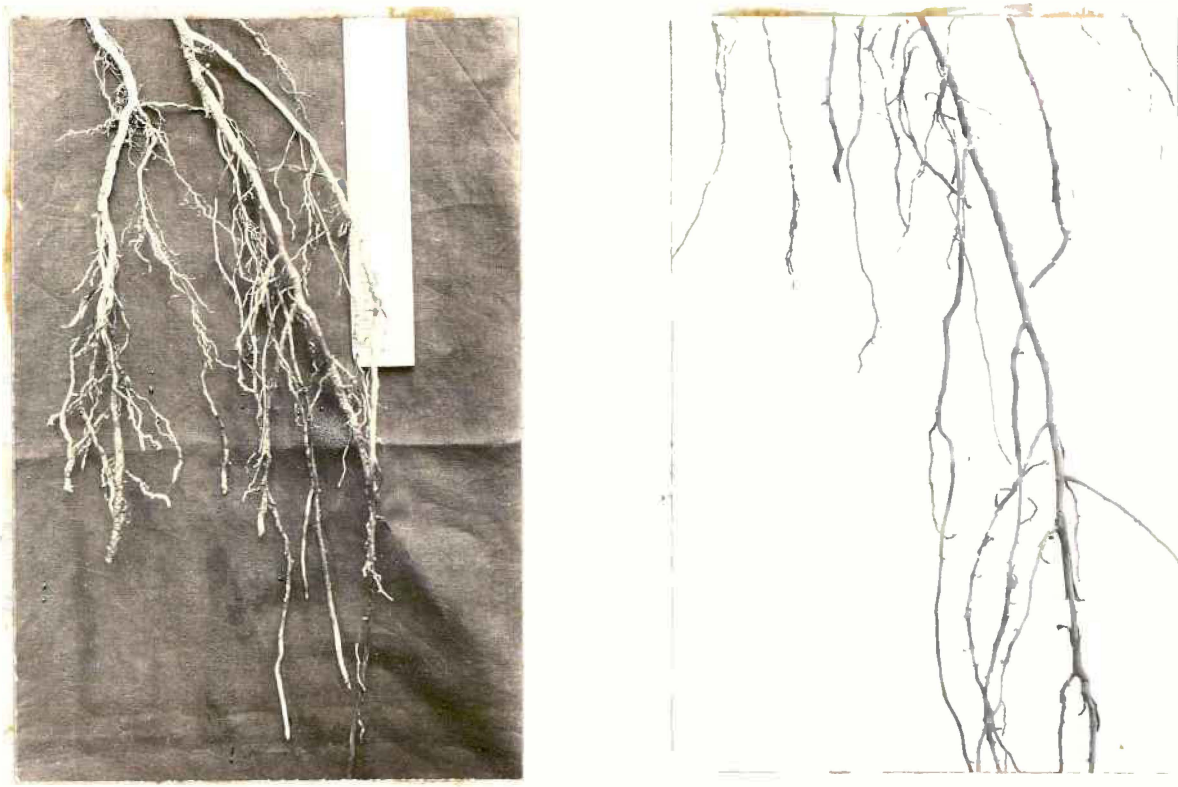

Figure 2. - A, Healthy root from a check tree; note the white root cap at the tip of practically every rootlet; B, dead root tips from a decadent tree; note decayed stubs and absence of the white root caps.

Table 1. RELATIONSHIP BETWEEN ROOT CONDITION AND HEMLOCK BORER INFESTATION

TREE NUMBER	Number of External Cankers	Percent Main Lateral Roots Alive					Percent of Root System Examined	Bark Area of Bole Sampled (Number of Square Feet)	Number of Samples	Average Number of Unsuccessful Borer Attacks per Square Foot				Average Number 1939 Larval Population per Square Foot		
		At Stump (root collar)	At 3 Feet	At 6 Feet	At 9 Feet[1]	Average for 9 Ft. Radius				Confined to Phloem	Wood Etched 0-2.9in.	Wood Etched 3-4.9in.	Wood Etched 5 - 9in.	In the Phloem	Etching the Wood	Mature and in Bark
GROUP I - Trees Showing Successful Attack																
4	77	-	-	-	-	10[2]	-	9.52	5	90	5.9	0.1	0	0	65.0	5.4[5]
20	50	8	10	10	0	7	29	6.98	5	22	0.7	0.1	0	0.6	44.0	7.4
27	50	1	0	0	0	0	82	9.55	6	90	0	0	0	2.1	60.0	.5
23	48	50	40	40	33	41	29	11.01	6	30	2.4	1.7	1.1	17.0	14.0	0
17	69	65	60	45	25	49	50	6.10	5	62	2.9	2.8	1.0	0	31.0	0
26	37	55	45	46	0	37	23	8.36	6	69	0	0	0	1.0	32.0	0
TOTAL	331									363	11.9	4.7	2.1	20.7	246.0	13.3
Aver.	55.2	36	31	28	12	24.0	34			60.5	2.0	0.8	.35	3.5	41.0	2.2
GROUP II - Trees Showing Unsuccessful Attack																
15	50	87	68	41	34	58	33	8.95	5	35	3.1	0	0	2.3	3.6	0
16	39	95	100	98	75	92	30	8.63	5	37	2.8	0.1	0	0.9	2.3	0
19	45	100	80	75	57	78	50	5.21	4	8	2.7	1.3	0	2.3	5.6	0
24	19	100	100	100	92	98	33	9.01	4	25	0.9	0.6	0.6	0	0	0
2	--	87	83	72	58	75	33	-[3]	-	-	-	-		-	-	-
TOTAL	153									105	9.5	2.0	0.6	5.5	11.5	0
Aver.	38.3	94	86	77	63	80.2	35			26.2	2.4	0.5	0.15	1.4	2.9	0
GROUP III - Check Trees																
25	42	100	100	100	100	100	29	10.70	6	28	2.4	0.4	0.3	0	0.1	0
14	45	100	100	100	100	100	33	6.59	4	1	1.5	0.4	0	0	0.3	0
18	14	100	100	100	95	99	30	9.89	5	15	1.0	0	0	0.1	1.3	0
22	125	100	100	100	100	100	31	8.99	5	1	0.2	0.8	0	1.3	2.7	0
21	40	100	100	100	100	100	34	7.52	5	2	0.3	0.4	0	2.3	0.9	0
TOTAL	266									47	5.4	2.0	0.3	3.7[4]	5.3[4]	0
Aver.	53.2	100	100	100	99	99.8	32			9.4	1.1	0.4	0.06	0.9	1.1	0

1. Percentage calculated for each unit distance based on the number of roots actually examined. Of the roots examined 69 percent reached a distance of 9 feet or more; the remaining 31 percent were either rotted off before they reached this distance or they entered the soil at such an angle that the excavation did not expose them for a linear length of 9 feet.
2. Examination of 20 roots of tree 4, which were 2.5 inches or ever in diameter revealed only 2 with living cambium at the root collar.
3. Extensive barking of the lower part of tree 2 failed to show any borer attack; the tree was selected because of Armillaria infection at the root collar.
4. Practically all the attacks shown in these columns occurred after the trees were cut.
5. Thirty-five beetles emerged from the basal 10 feet of the trunk of tree 4 during July and August. These averaged 1 emergence to approximately 2 square feet of bark.

Table 2. PRECIPITATION RECORDS

YEAR	ANNUAL						GROWING SEASON (April through August)					
	ANTIGO		SHAWANO		WAUSAU		ANTIGO		SHAWANO		WAUSAU	
	Precipitation in inches	Departure from Normal	Precipitation in inches	Departure from Normal	Precipitation in inches	Departure from Normal	Precipitation in inches	Departure from Normal	Precipitation in inches	Departure from Normal	Precipitation in inches	Departure from Normal
1930	27.09	-2.93	24.12	-4.26	27.15	-4.96	15.72	-2.01	13.60	-2.39	16.92	-1.21
1931	27.38	-2.17	30.42	+1.60	27.57	-4.54	11.36	-6.22	10.91	-5.14	12.39	-5.74
1932	25.89	-3.66	25.22	-3.60	23.05	-9.10	11.22	-6.36	12.28	-3.77	10.58	-7.55
1933	24.55	-5.00	26.35	-2.47	25.09	-7.02	13.77	-3.81	13.99	-2.06	13.97	-4.16
1934	34.54	+4.99	31.38	+2.56	34.06	+1.95	16.82	-0.76	14.05	-2.00	15.71	-2.42
1935	27.62	-1.93	26.97	-1.85	30.67	-1.44	15.58	-2.00	14.48	-1.57	18.23	+0.10
1936	27.96	-1.49	28.16	-1.58	27.43	-3.47	16.70	-0.48	12.31	-4.20	15.74	-1.93
1937	25.84	-3.61	29.14	-0.60	25.27	-5.63	11.63	-5.55	11.42	-5.09	12.25	-5.42
TOTAL DEP. 1930-1937		-15.80		-10.20		-34.21		-27.19		-26.22		-28.33
TOTAL DEP. in PERCENT								-19.4		-20.3		-19.7
1938*	42.04	+12.59	40.06	+10.32	48.72	+17.82	22.85	+5.67	18.76	+2.25	29.53	+11.86
1939*							16.86	-0.32	15.06@	-1.45	19.18	+1.51

*The precipitation figures for 1938 and 1939 are added to this table in order to include the records during the progress of the hemlock borer investigation.

@Complete 1939 precipitation records from the Shawano Weather Bureau Station are not available for the growing season. The records from the Indian Service, at Neopit, have been substituted and the departure from normal has been arbitrarily calculated on the basis of the previous records at Shawano.

tion, the records for the growing seasons (April through August) show even more clearly the severe effect of these drought periods because, during this same period, precipitation below normal was recorded every year at all these stations except at Wausau in 1935. The lowest precipitation for a single growing season in this period was 10.55 inches (7.55 inches below normal) at Wausau in 1932. The summer droughts of 1931, 1932, and 1937 were most severe, and the total of the departures for the growing seasons during the entire 8-year period at these three stations was -27.19, -26.22 and -28.33 inches respectively, representing average minus departures of 19.4, 20.3 and 19.7 percent. Although no precipitation records for the Reservation are available for this period, the "minus" departures from normal for the growing seasons of 1931, 1932, 1936, and 1937 were very marked as the records of the Forestry Department show unusually severe fire hazard during these growing seasons.

High winds, some of near tornado velocity, occurred on the Reservation during the 1930-37 period. Particularly serious blow-down damage occurred during 1933, 1934, and 1936, and resulted in the loss of 80,000,000 board feet of timber.[6] Periods of severe hot, dry weather frequently preceded these high winds. For example, on July 11, 1936, the temperature at Keopit reached 110° F. in the shade. This unusually severe heat wave was broken by a tornado-like wind that knocked down 30,000,000 board feet of timber on the Menominee Reservation alone. In addition to the timber loss caused by the mechanical effect of these winds, there was

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6. Heritage, William. Forestry accomplishments in the Indian Service in the Lake States. Jour. Forestry 38: 717. 1939.

undoubtedly considerable loss caused by the sudden release of the understory trees to full sunlight, heat, and high evaporation at a time when there was a deficiency of soil moisture. The shallow rooted hemlock trees particularly suffered severe injury from heat and exposure. Baker[7] states that under these conditions trees suffer considerable injury or actual death.

This investigation showed that under these conditions of drought and exposure the root tips were apparently the first organs to die and that gradually the larger roots became weakened and decadent. (Fig. 3.) Busgen and Munch[8], referring to the works of Strasburger, Hansen and Böhm, state that water absorption may take place through dead roots, which partially explains why the crowns remain alive longer than the roots. Miller[9], in summing up the work of various authors, shows that when the water content of the leaves of a plant is reduced appreciably, due to a limited water supply, a marked reduction in photosynthesis occurs. Baker[10], in discussing the transportation of elaborated foods, states, "Under any famine of elaborated foods, the cambium of the lower trunk and roots suffers most, so that narrow rings appear during unfavorable years most often in the lower bole". Thus, under drought conditions, the roots tend to suffer from starvation whenever there is insufficient water in the crown for the normal assimilation of food. With the death of the roots, attacks

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7. Baker, F. S. "Theory and Practice of Silviculture." P. 161. McGraw-Hill Book Co. 1934.

8. Busgen, M. and Munch E. "Structure and Life of Forest Trees." English translation by Thomas Thomson. P. 312. John Wiley & Sons, Inc. 1929.

9. Miller, E. C., "Plant Physiology." P. 467. McGraw-Hill Book Co. 1931.

10. Baker, F. S., "Theory and Practice of Silviculture." P. 66. McGraw-Hill Book Co. 1934.

Figure 3. - A, Sections of bark removed from roots of tree 20 in July 1939 showed practically all of the roots dead and bearing the mycelial fans of the shoestring fungus. This tree was successfully attacked by the hemlock borer for the first time in 1936; B, dead roots, rotted by the shoestring fungus. This tree had no successful borer attacks in July 1939.

by diseases and insects become possible. This was found to be the case at the Menominee Reservation.

Cankers were found on many of these roots and appeared to be as prevalent on the roots of healthy trees as on those which were dead or dying. The cankers which could be detected by external examination were noted, and no correlation was found between the number present and the degree of infection by the shoestring root rot. (Table 1.) Examination of the cankers on the live roots of the check trees showed that many were not infected by the root rot and were possibly caused by frost action, since the hemlock is very shallow-rooted. Other check tree cankers which obviously had been infected by the root rot several years previous to the investigation had healed and calloused over. (Fig. 4.) This substantiates the general belief that this fungus is secondary and can successfully attack and kill only weakened trees.

A strip cruise of 1.9 acres was made to determine the amount of root and collar infection apparent on hemlock trees in a virgin stand. The strip was 19 chains long and 1 chain wide and adjoined a stand in which part of the root examination was done. The presence of infection was determined principally by external examination of the lower trunk and those portions of the root collar which could be readily exposed by digging away the leaf litter with a sharpened stick. Where infection was indicated by the moist discolored bark areas, verification was made by removing the bark. Subsequently, fungus cultures isolated from both root and collar infections proved to be Armillaria mellea in the majority of cases. Of the 405 trees included in the survey strip, 8.4 percent had either disease-infected areas or root rot near the soil line. The percentage for trees over 10 inches DBH was 18. These percentages are conservative as indicators of the diseased condition of the trees

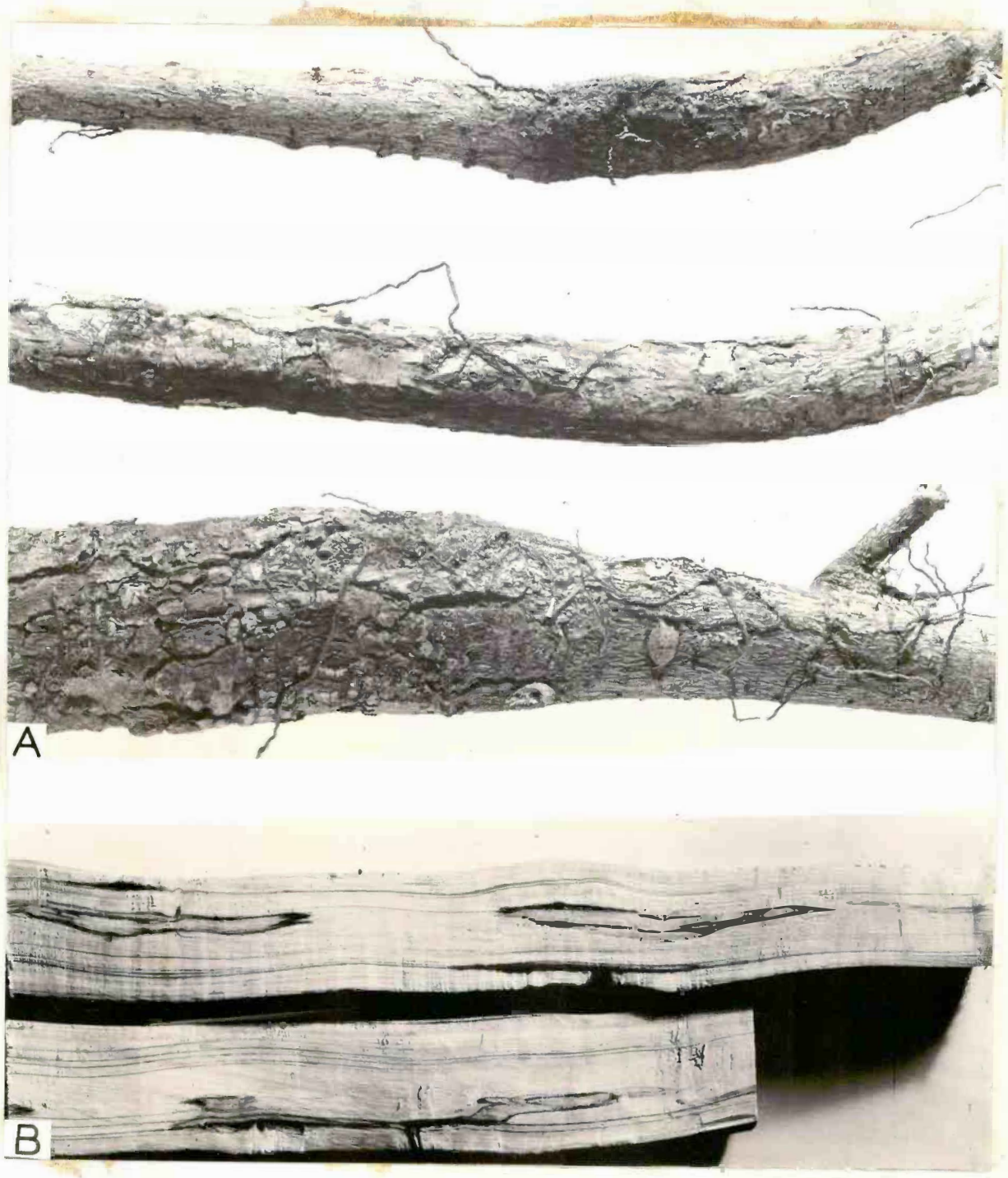

Figure 4. - A. Healed cankers and the rhizomorphs, or shoestrings, of Armillaria mellea; B. Longitudinal sections of cankered root, showing point of entrance of infection.

after the drought period because the majority of the root rot infections are not apparent at the soil line until they are in the more advanced stages.

Table 1 shows that successful 1938 borer attack was found only on trees having 10 percent or less of their roots systems alive at the time the roots were examined. The presence of mature larvae in hibernation cells in the bark of trees 4, 20, and 27 in August 1939 and a few 1939 beetle emergence holes on number 4 indicated that all 3 had had light successful attacks in 1938. These trees had not had any successful attack prior to 1938 and practically no unsuccessful attacks. Two of the trees showed heavy initial unsuccessful 1938 attacks (90 or more galleries per square foot of bark area), but all 3 trees had only very light advanced unsuccessful attack (0.1 galleries or less per square foot) and light successful attack. (The terms used in this paper to refer to certain stages of attack, which are shown in fig. 5, are defined as follows: "Initial unsuccessful attacks" are those which produce only "initial galleries", which, in turn, are those galleries which are confined entirely to the phloem tissue, or, if they extend to the wood, fail to etch its surface for more than 3 inches, due to the early death of the larvae. "Advanced unsuccessful attacks" are those which produce "unsuccessful galleries", which, in turn, are those galleries that etch the wood for more than 3 inches but were never completed because of the premature death of the larvae. "Successful attacks" occur when the larvae have completed their feeding and have developed to the adult stage and emerged, or are still present in their pupal cells preparatory to emerging.) The abundance of larvae etching

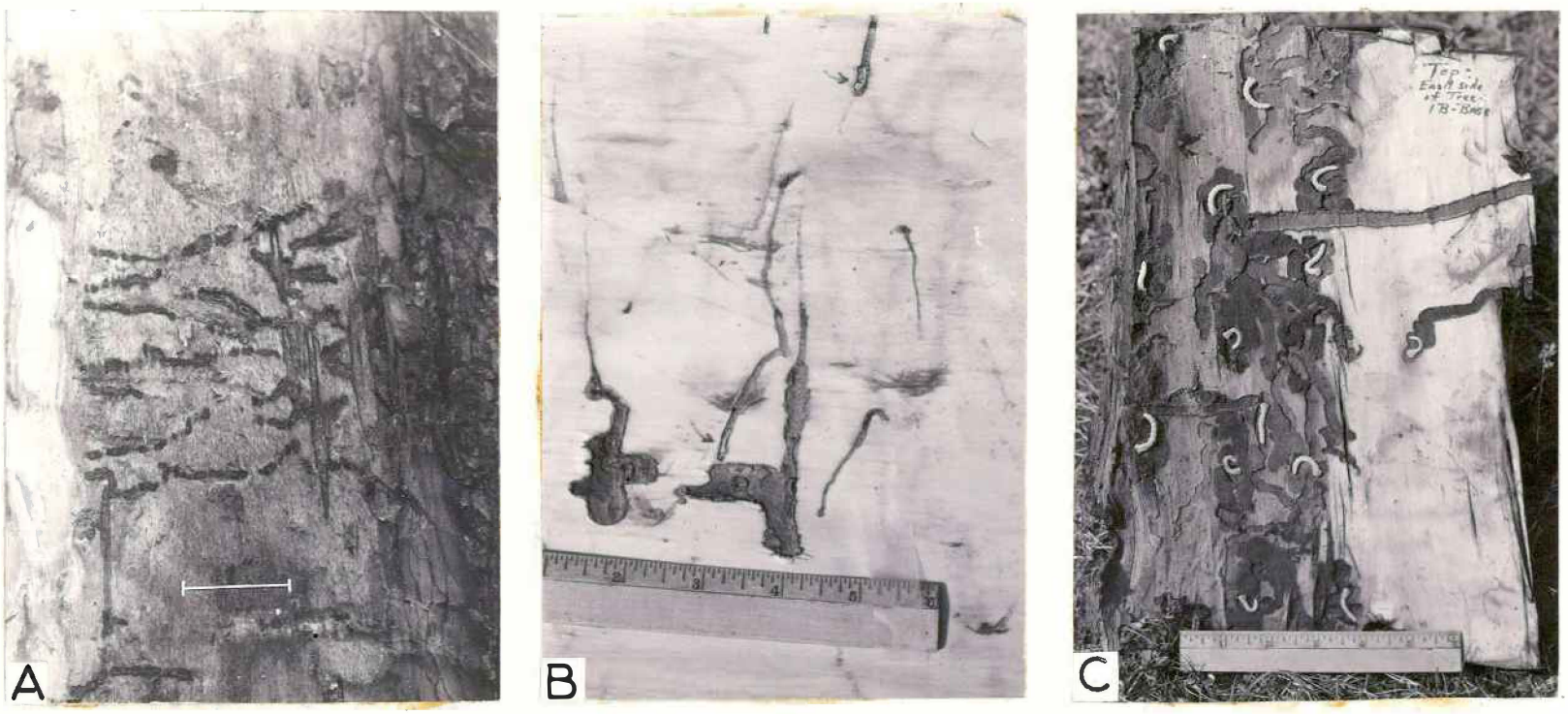

Figure 6.- Degrees of attack by the eastern hemlock borer: A, Initial unsuccessful attack in the phloem tissue; B, initial and advanced unsuccessful attack etching the wood tissue; C, successful attack and mature larvae nearing the successful attack stage.

the surface of the wood and the comparative absence of larvae in the phloem indicate that the majority of the borer population of these trees was from early 1939 ovipositions.

Trees 17, 23 and 26, which were successfully attacked by the borer for the first time in 1939, had only 35 to 50 percent of their root systems alive at the time the roots were examined. They were intermediate, with respect to both root condition and borer infestation, between the trees showing successful 1938 borer attack and those showing only unsuccessful attack. These trees showed more unsuccessful attack in 1938 and fewer successful attacks in 1939 than did trees 4, 20, and 24. (Fig. 8.) Unsuccessful attack galleries were prevalent in trees having 60 to 80 percent of their root systems alive. They were occasionally found, however, on trees having practically no dead roots. When such galleries are very numerous, they may be regarded as a certain indicator that the root system of the tree is in such poor condition that the tree will die soon, usually within 2 or 3 years. When such a gallery is found only occasionally, it indicates that the tree is not vigorous but is still capable of recovery if growth conditions become more favorable. Trees 24 and 25 were found to be recovering from light to medium unsuccessful attack in 1938 and had practically no 1939 attack. The 1938 unsuccessful attack on these trees totaled, per square foot, 2.6 galleries that had etched the wood and 26 galleries confined entirely to the phloem. Probably good root condition was the main factor making possible this apparent remarkable recovery. The drought seasons of 1936 and 1937 and the succeeding favorable seasons of 1938 and 1939 were probably responsible for the temporary loss of and the regaining of vigor in these trees. It is unusual, however, to find

trees regaining their vigor after having been in a condition which made possible this degree of attack. Numerous instances were observed of trees which were alive and apparently normal after having suffered light wood etching, when no larvae were successful in completing development. Such trees were found principally in areas severely injured by blowdowns. The wood etching on these trees did not usually exceed 1.5 galleries per square foot, and all had been completely healed over by the wood laid on in the years following attack.

The trees in group II in table 1 show less difference between the number of 1939 attacks etching the wood and the number of late summer ovipositions still in the phloem than do the trees in group I. A period of about 4 weeks elapsed between the felling and the larval examinations of trees 15, 16, and 19, and all the phloem larval population and possibly half of the larval population which had reached the wood had hatched since the trees were cut. It is very improbable that any of these larvae would have completed their life cycles if the trees had not been felled.

The root systems of all but one check tree were apparently 100 percent alive and the average for this one exception was 99 percent. Although Armillaria had been present in cankers on the roots of all the trees, all of the cankers so affected, with the exception of a few on tree 22, were completely calloused over. The healthy callous tissue over these old infections indicates that this rot is not able to kill healthy, vigorous roots and should, therefore, be considered secondary. At the time they were felled these trees had no successful borer attacks and few unsuccessful attacks. A few small larvae were found in August and as a period of 4 weeks had elapsed between the root washing operation and the

quantitative examination for the larval population, there was ample time for oviposition and the development of the larvae which were present. No medium- or large-sized larvae were found, showing that there had not been any successful attack prior to the felling of the trees.

This investigation showed that on the Menominee Indian Reservation hemlock borer attack was not successful until the trees were in a dying condition, evidenced by the fact that the majority of their roots were dead. Since the hemlock borer and the shoestring root rot have been shown to be secondary, the most probable factor causing the decadence is drought. Further evidence of this fact is that in many cases the annual rings were dropped out at the base for periods of 2 to 5 years before the death of the trees, although rings were laid on during these years in the upper portions of the trunks. Many trees with apparently healthy crowns except for a slight thinning and yellowing of the foliage had practically all their root systems dead and mycelial fans of the shoestring root rot under the bark at the root collar before there was successful borer attack.

Summary

1. Successful 1938 borer attack was found only on trees having 10 percent or less of their root systems alive. These trees had no successful attack and practically no unsuccessful attack prior to 1938.

2. Trees which were successfully attacked by the borer for the first time early in 1939 were found to have only 35 to 50 percent of their root systems alive.

3. Check trees had 99 to 100 percent of their root systems alive, based on sample roots examined, and few unsuccessful borer attack galleries.

4. Active Armillaria infection was present on all of the trees having successful 1938 borer attack. Active infection was also present on trees having early 1939 successful borer attack.

5. There is evidence that in many cases the Armillaria infection was present prior to the initiation of successful borer attack. Thus, in such instances, successful attack by the borer was secondary to the initiation of successful Armillaria infection.

6. Observations made on the Menominee Indian Reservation indicate that root rots play a secondary role in the death of the hemlock. The fact that healthy trees contain numerous small root cankers which, in the majority of cases, heal over satisfactorily even though the shoestring root rot is present seems to be good substantiating evidence. Under forest conditions Armillaria mellea probably can successfully attack only weakened trees.

7. Lack of moisture during the 1930-37 period was the primary cause for the heavy hemlock mortality on the Reservation.